A Wafer Transfer Technology for MEMS Adaptive Optics

Eui-Hyeok Yang and Dean V. Wiberg
Jet Propulsion Laboratory, 4800 Oak Grove Drive, Pasadena, CA 91109-8099
Eui-Hyeok.Yang@jpl.nasa.gov ph: +1-818-354-7059 fx: +1-818-393-6047

Background: Adaptive optics has made it possible to obtain images of the living human retina with unprecedented resolution, enabling researchers to see the individual receptors involved in vision. For astronomy, where light levels are often very low, this means fainter objects can be detected and studied. Deformable mirrors in AO systems are reflecting elements that have arrays of actuators that deform the mirrors to compensate for wavefront distortions.

Problems and Solutions: Previously reported MEMS deformable mirrors have marginal surface quality and/or limited stroke or large inter-actuator coupling [1-3]. Therefore, a new deformable mirror concept has been proposed (Fig. 1). The device consists of a transferred continuous membrane mirror supported by deformable actuators, so that very low inter-actuator coupling is achieved, while providing an optical quality mirror surface and a high stroke actuation. In order to realize this concept, a sheet of membrane (with surface area > 70 cm^2) was transferred [4] in order to overcome feasibility issues of other wafer transfer studies [5-10]. In this paper, electrostatic actuators array is fabricated by the wafer transfer and the surface quality of a transferred silicon membrane is characterized.

Fabrication: A 1 μm thick corrugated polysilicon membrane has been transferred onto an electrode wafer to show the feasibility of the proposed wafer transfer technology. A polysilicon membrane and a single crystal silicon membrane have been transferred, respectively. An SOI wafer and a silicon wafer are used as the carrier and electrode wafers, respectively. Wafers are patterned and etched to define electrodes. The polysilicon layer is deposited on the SOI wafer (Fig. 2 (a)). The wafers are hermetically bonded by using indium bumps (4 KPa at 156 °C) (Fig. 2 (b)). The backside of the SOI wafer is fully etched away in a 25 wt % TMAH bath (Fig. 2 (c)). The buried oxide is then removed by using HF droplets after an O_2 plasma cleaning (Fig. 2 (d)). The SOI top silicon layer is removed and the SF_6 plasma with a shadow mask selectively etches the polysilicon membrane to define actuator patterns (Fig. 2 (e)). Electrostatic actuators with various electrode gaps have been fabricated and characterized.

Characterization: Fig. 3 shows SEM photographs of a 1 μm thick membrane, which has been successfully transferred onto the electrode wafer. The gap between the membrane and electrode substrate is very uniform (+/- 0.1 μm across a wafer diameter of 100 mm, provided by optimizing the bonding control). A WYKO RST Plus optical profiler has been used to measure the static deflection and the surface profile of transferred membranes. The fabricated polysilicon actuator with an electrode gap of 1.5 μm shows a vertical deflection of 0.37 μm at 55 V (Fig. 4). The surface profile of a transferred single crystal silicon membrane has been measured and compared with that of a typical silicon wafer (Fig. 5). Figs. 6 (a) and (b) show the power spectral density data of surfaces of a transferred silicon membrane and a silicon wafer, respectively, indicating that the surface quality of a transferred membrane is as good as that of a typical silicon wafer. This ensures that the optical quality deformable mirror can be obtained if the optical quality silicon wafer is used for the membrane transfer.

Summary: Fabrication and characterization of electrostatic actuators by the wafer-level membrane transfer technique has been demonstrated. A 1 μm thick silicon membrane, 100 mm in diameter, has been successfully transferred without using adhesives or polymers (i.e. wax, epoxy, or photoresist). The surface quality of a transferred silicon membrane is characterized for the deformable mirror technology for the applications to various areas such as laser beam steering, visual science and both space and earth bound ultra large segmented telescopes.

References

1. T. Bifano *et al.*, Opt. Eng. 36(5) p.1354, 1997. 2. J. Mansell *et al.*, Proc. SPIE, Vol. 4124, p.15 3. G. Vdovin, *SPIE*, Kona, Hawaii, March 1998, p. 902, . 4. E.H. Yang *et al.*, Proc. MEMS '01, p. 80. 5. T. Bell *et al.*, Proc. MEMS '98, p. 251. 6. C. Keller *et al.*, Proc. MEMS '97, p. 72. 7. A. Singh *et al.*, IEEE J. MEMS, p. 27, 1999. 8. K. Harsh *et al*, Proc. MEMS '99, p.273. 9. T. Akiyama *et al*, IEEE J. MEMS, p. 65, 1999. 10. H. Nguyen *et al*, Proc. MEMS '2000, p. 628

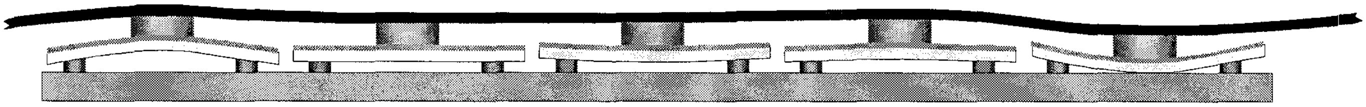


Fig. 1 The concept of a MEMS deformable mirror with a continuous silicon mirror membrane.

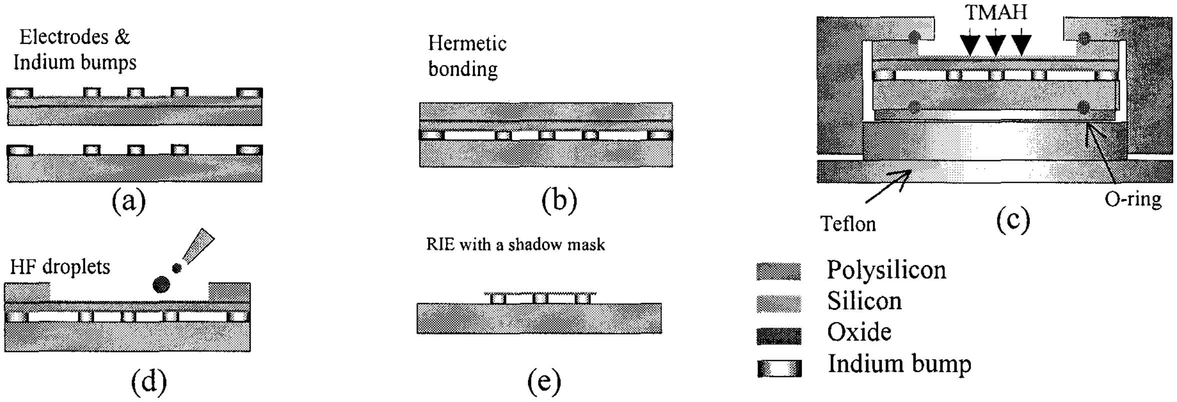


Fig. 2 The membrane transfer process for the fabrication of the high stroke MEMS deformable mirror. The successive layer transfer process is identical with the first layer transfer process except for the use of a shadow mask to place Indium bumps over deformable actuators. (a) Polysilicon deposition, electrode definition & Indium evaporation. (b, c, d) Bonding & etching. (e) Defining actuator membrane. (f) Successive layer transfer.

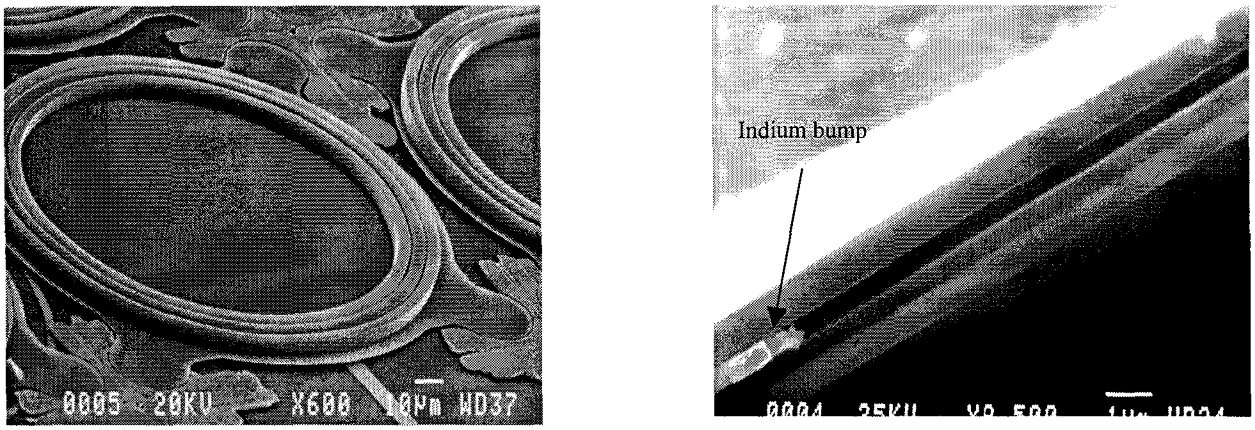


Fig. 3 The SEM photographs of the transferred membrane actuator. (a) The transferred membrane corrugated deformable actuator. (b) The cross sectional view of a transferred membrane actuator.

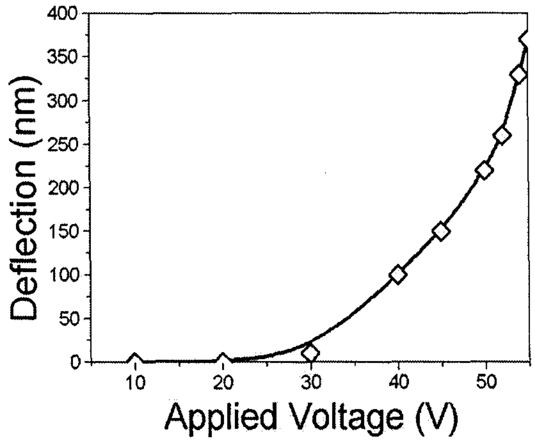


Fig. 4 The deflection characteristic of a transferred membrane actuator.

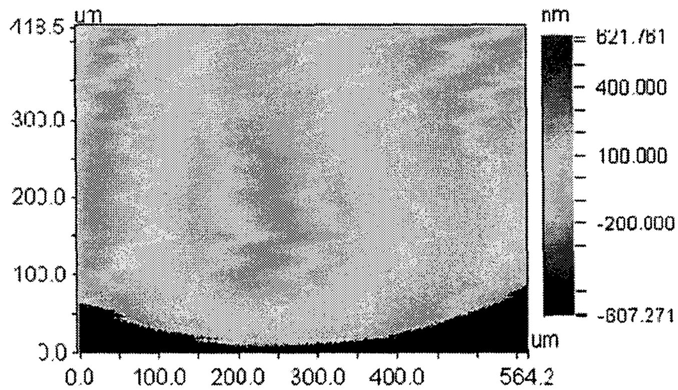
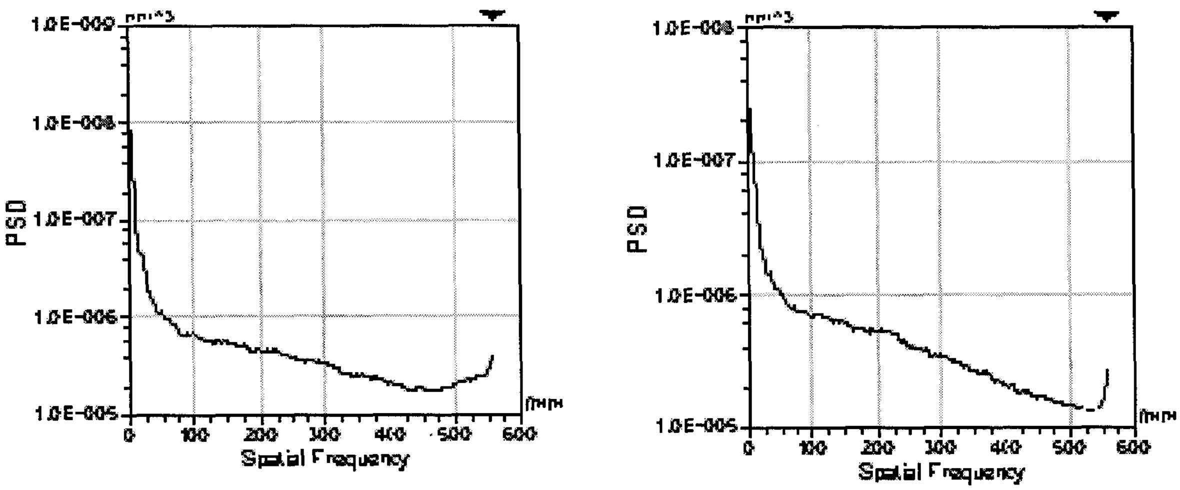


Fig. 5 The surface profile of a transferred single crystal silicon membrane.



(a)

(b)

Fig. 6 The power spectral density data of the silicon surfaces. (a) A transferred membrane. (b) A silicon wafer.